Recent Results on $\psi(3770)$ Physics at BES

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There are about 33, 6.5 and 1.0 pb^{-1} of e^+e^- annihilation data have been taken around the center-of-mass energies of $\sqrt{s}$ = 3.773 GeV, at $\sqrt{s}$ = 3.650 GeV and at $\sqrt{s}$ = 3.6648 GeV, respectively, with the BES-II detector at the BEPC collider. By analyzing these data sets, we have measured the branching fraction for $\psi(3770) \to$ non-$D\bar{D}$ by several different methods; and have observed an anomalous line shape of $\sigma^{e^+e^-\to\text{hadrons}}$ in energy region from 3.65 to 3.87 GeV; and have measured the line shapes of the D^+D^-, $D^0\bar{D}^0$ and $D\bar{D}$ production and together with the ratios of the production rates of D^+D^- and $D^0\bar{D}^0$ in e^+e^- annihilation around the $\psi(3770)$ resonance.

1 Introduction

The $\psi(3770)$ is the lowest mass charmonium resonance above the open charm pair $D\bar{D}$ production threshold. Traditional charmonium theories expect that it decays almost entirely into pure $D\bar{D}$ pairs. However, before the measurements from BES and CLEO Collaborations, there is a long standing puzzle that the observed cross section $\sigma^{\rm obs}_{\psi(3770)}$ for $\psi(3770)$ production is not saturated by the observed cross section $\sigma^{\rm obs}_{D\bar{D}}$ for $D\bar{D}$ production at the $\psi(3770)$ peak [1]. Recently, CLEO Collaboration measured the $e^+e^- \to \psi(3770) \to {\rm non}-D\bar{D}$ cross section to be $(-0.01 \pm 0.08^{+0.41}_{-0.30})$ nb [2]. However, BES measured the branching fraction for $\psi(3770) \to rmnon - D\bar{D}$ by analyzing several different data samples and different methods to be $(14.7 \pm 3.2)\%$ [3,4,5,6,7] with the assumption that there is only one traditional $\psi(3770)$ resonance in the energy region between 3.700 and 3.872 GeV. While, up to now, the sum of the measured branching fractions for $\psi(3770) \to$ exclusive non$-D\bar{D}$ decays is not more than 2% [8,9,10,11,12,13]. To better understand the situation, we examine the line shape of the cross section for $e^+e^- \to$ hadrons in the energy region from 3.650 to 3.872 GeV, and measure the line shapes of the D^+D^-, $D^0\bar{D}^0$ and $D\bar{D}$ production and the ratios of the production rates of D^+D^- and $D^0\bar{D}^0$ in e^+e^- annihilation at $\psi(3770)$ resonance. These measurements are made by analyzing about 33, 6.5 and 1.0 pb^{-1} of e^+e^- annihilation data sets taken around the center-of-mass energies of $\sqrt{s}$ = 3.773 GeV, at $\sqrt{s}$ = 3.650 GeV and at $\sqrt{s}$ = 3.6648 GeV with the BES-II detector at the BEPC collider. The data sets taken around $\sqrt{s}$ = 3.773 GeV include the data sets of 17.3 pb^{-1} taken at $\sqrt{s}$ = 3.773 GeV, the precision cross section scan data sets taken in March 2001, during March to April 2003 and during December 2003 to January 2004.

Table 1: The measured branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ and non$-D\bar{D}$ decays.

$\mathcal{B}[\psi(3770) \to](\%)$	$D^0\bar{D}^0$	D^+D^-	$D\bar{D}$	non$-D\bar{D}$
Ref.[3]	$49.9 \pm 1.3 \pm 3.8$	$35.7 \pm 1.1 \pm 3.4$	$85.5 \pm 1.7 \pm 5.8$	$14.5 \pm 1.7 \pm 5.8$
Ref.[4]	$46.7 \pm 4.7 \pm 2.3$	$36.9 \pm 3.7 \pm 2.8$	$83.6 \pm 7.3 \pm 4.2$	$16.4 \pm 7.3 \pm 4.2$
Ref.[5]				$13.4 \pm 5.0 \pm 3.6$
Ref.[6]				$15.1 \pm 5.6 \pm 1.8$
PDG 2008[7]	48.7 ± 3.2	36.1 ± 2.8	85.3 ± 3.2	14.7 ± 3.2

2 Measurements about $\mathcal{B}(\psi(3770) \to \text{non} - D\bar{D})$

Assuming that there is only one traditional $\psi(3770)$ in the energy region between 3.700 and 3.872 GeV, we measure the branching fraction for $\psi(3770) \to rmnon - D\bar{D}$ decays by analyzing several different data samples and different methods. The measured branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ and non$-D\bar{D}$ decays are compared in Tab. 1. After the $\psi(3770)$ resonance was discovered for more than thirty years, Particle Data Group 2008 [7] gives the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^- and $D\bar{D}$ decays for the first time. They are $\mathcal{B}[\psi(3770) \to D^0\bar{D}^0] = (48.7 \pm 3.2)\%$, $\mathcal{B}[\psi(3770) \to D^+D^-] = (36.1 \pm 2.8)\%$ and $\mathcal{B}[\psi(3770) \to D\bar{D}] = (85.3 \pm 3.2)\%$, which indicates that the branching fraction for $\psi(3770) \to \text{non} - D\bar{D}$ decays is $(14.7 \pm 3.2)\%$.

These measurements imply that the $\psi(3770)$ could substantially decay into non$-D\bar{D}$ final states, which might greatly challenge the traditional theories. Otherwise, there may exist some other effects in the energy region around $\psi(3770)$ resonance which are responsible for the large branching fraction for $\psi(3770) \to \text{non} - D\bar{D}$ decays.

3 Anomalous line-shape of $\sigma^{e^+e^- \to \text{hadrons}}$ in energy region from 3.65 to 3.87 GeV

To understand why the measured branching fraction for $\psi(3770) \to \text{non} - D\bar{D}$ is substantially larger than 2%, we examine the line shape of the cross section for $e^+e^- \to$ hadrons in the energy region from 3.650 to 3.872 GeV, by analyzing the precision cross section scan data sets taken in March 2003 and during December 2003 to January 2004. Fig. 2 in Ref. [14] shows the measured observed cross sections for $e^+e^- \to$ hadrons versus the nominal center-of-mass energies. In the figure, we can see that the slope of the high-energy side of the peak is substantially larger than that of the low-energy side. This phenomenon is inconsistent with the traditional expectation under the assumption that there is only one simple $\psi(3770)$ resonance in this energy region. To investigate this situation, we fit the measured observed cross sections for $e^+e^- \to$ hadrons with the following solutions, respectively. Firstly, we suppose that there are two amplitudes and ignore the possible interference between them. Secondly, we suppose that there are two amplitudes completely interfering with each other. Thirdly, we assume that there are two amplitudes of G(3900) [15,16] and $\psi(3770)$ resonance interfering with each other. Finally, we carry out the treatment as a comparison solution that there is only one simple $\psi(3770)$ resonance. The fitted results are summarized in Tab. 2. The details about the fits can be found in Ref. [14]. By comparing the fitted results, we can obtain the better hypothesis to describe the anomalous line shape of the cross sections for $e^+e^- \to$ hadrons in the energy region from 3.700 to 3.872 GeV. The signal significance for the two structure hypotheses are 7.0σ and 7.6σ for solution 1 and solution 2. The significance of the interference between the two amplitudes is 3.6σ. Fig. 2 in Ref. [14] shows the fit to the observed cross sections for $e^+e^- \to$ hadrons for solution 2. Fig. 3 (a) in Ref.[14] shows the fits to the observed cross sections for $e^+e^- \to$ hadrons for the three

Table 2: The fitted results, where M, $\Gamma^{\rm tot}$ and $\Gamma^{\rm ee}$ are the mass, total, and leptonic widths of resonance(s), σ_G is standard deviation of $G(3900)$, ϕ is the phase difference between the two amplitudes and **AM** stands for amplitude(s). ndof denotes number of degrees of freedom.

Quality	two **AM** (solution 1)	two **AM** (solution 2)	one **AM**	$\psi(3770)$ and $G(3900)$ **AM** (solution 3)
χ^2/(ndof)	125/103=1.21	112/102=1.10	182/106=1.72	170/104=1.63
$M_{\psi(3686)}$ [MeV]	$3685.5 \pm 0.0 \pm 0.5$	$3685.5 \pm 0.0 \pm 0.5$	$3685.5 \pm 0.0 \pm 0.5$	$3685.5 \pm 0.0 \pm 0.5$
$\Gamma^{\rm tot}_{\psi(3686)}$ [keV]	$312 \pm 34 \pm 1$	$311 \pm 38 \pm 1$	$304 \pm 36 \pm 1$	$293 \pm 36 \pm 1$
$\Gamma^{\rm ee}_{\psi(3686)}$ [keV]	$2.24 \pm 0.04 \pm 0.11$	$2.23 \pm 0.04 \pm 0.11$	$2.24 \pm 0.04 \pm 0.11$	$2.23 \pm 0.04 \pm 0.11$
M_1 [MeV]	$3765.0 \pm 2.4 \pm 0.5$	$3762.6 \pm 11.8 \pm 0.5$	$3773.3 \pm 0.5 \pm 0.5$	$3774.4 \pm 0.5 \pm 0.5$
$\Gamma^{\rm tot}_1$ [MeV]	$28.5 \pm 4.6 \pm 0.1$	$49.9 \pm 32.1 \pm 0.1$	$28.2 \pm 2.1 \pm 0.1$	$28.6 \pm 2.3 \pm 0.1$
$\Gamma^{\rm ee}_1$ [eV]	$155 \pm 34 \pm 8$	$186 \pm 201 \pm 8$	$260 \pm 21 \pm 8$	$264 \pm 23 \pm 8$
M_2 [MeV]	$3777.0 \pm 0.6 \pm 0.5$	$3781.0 \pm 1.3 \pm 0.5$	...	3943.0(fixed)
$\Gamma^{\rm tot}_2$ [MeV]	$12.3 \pm 2.4 \pm 0.1$	$19.3 \pm 3.1 \pm 0.1$	...	...
or σ_G [MeV]	...	...	...	54(fixed)
$\Gamma^{\rm ee}_2$ [eV]	$93 \pm 26 \pm 9$	$243 \pm 160 \pm 9$	...	...
or C	...	...	...	0.243(fixed)
ϕ [degree]	...	$158 \pm 334 \pm 5$	...	$150 \pm 23 \pm 5$
f	$0.4 \pm 5.6 \pm 0.6$	$5.2 \pm 2.5 \pm 0.6$	$0.0 \pm 0.5 \pm 0.6$	$0.0 \pm 1.2 \pm 0.6$

solutions. Fig. 3 (b) in Ref.[14] shows the ratio of the residual between the observed cross section and the fitted value for the one $\psi(3770)$ amplitude hypothesis to the error of the observed cross section, which indicating that there is more likely some new structure in addition to $\psi(3770)$ resonance.

4 Measurement of the line shapes of $sigma^{D\bar{D}}(s)$ and $sigma^{D^+D^-}(s)/sigma^{D^0\bar{D}^0}$ around $\psi(3770)$ resonance

To investigate what on earth is responsible for the large branching fraction for $\psi(3770) \to {\rm non}-D\bar{D}$ decays which is beyond the expectation by the traditional theories, we measure the line shapes of the $D^0\bar{D}^0$, D^+D^-, and $D\bar{D}$ production and the ratios of the production rates of $D^0\bar{D}^0$ and D^+D^- in e^+e^- annihilation at $\psi(3770)$ resonance. These measurements are also helpful for the understanding the anomalous line shape of the cross section for $e^+e^- \to$ hadrons in the energy region from 3.650 to 3.872 GeV. These measurements are made by analyzing the precision cross section data sets taken in March 2001, during the period from March to April 2003, and during December 2003 to January 2004. Fig. 5 in Ref.[17] shows the observed cross sections for $e^+e^- \to D^0\bar{D}^0$, $e^+e^- \to D^+D^-$ and $e^+e^- \to D\bar{D}$ versus the nominal center-of-mass energies. In the figure, we can see that the line shapes of the cross section for $e^+e^- \to D^0\bar{D}^0$, $e^+e^- \to D^+D^-$ and $e^+e^- \to D\bar{D}$ are also anomalous, just like the line shape of the observed cross section for $e^+e^- \to$ hadrons. Fig. 6 in Ref.[17] shows the measured ratio of the observed cross section for $e^+e^- \to D^+D^-$ relative to the observed cross section for $e^+e^- \to D^0\bar{D}^0$ versus the nominal center-of-mass energies.

5 Summary

Using the e^+e^- data sets of about 33, 6.5 and 1.0 pb^{-1}, respectively, taken around the center-of-mass energies of $\sqrt{s} = 3.773$ GeV, at $\sqrt{s} = 3.650$ GeV and at $\sqrt{s} = 3.6648$ GeV with the BES-II detector at the BEPC collider, BES Collaboration measure the branching fraction for $\psi(3770) \to {\rm non}-D\bar{D}$ decays by analyzing several different data samples and different methods

with assumption that there is only one traditional $\psi(3770)$ in the energy region between 3.700 and 3.872 GeV. We observe an anomalous line shape of the cross section for $e^+e^- \to$ hadrons in the energy region from 3.650 to 3.872 GeV. We measure the line shapes of the D^+D^-, $D^0\bar{D}^0$ and $D\bar{D}$ production and the ratio of the production rates of D^+D^- and $D^0\bar{D}^0$ in e^+e^- annihilation at $\psi(3770)$ resonance. These indicate that there may exist a new structure in addition to one simple $\psi(3770)$ resonance in the energy region between 3.700 and 3.872 GeV or there are some unknown dynamics effects distorting the line shape of the cross sections for $e^+e^- \to$ hadrons and $D\bar{D}$.

Acknowledgments

The BES collaboration thanks the staff of BEPC for their hard efforts. This work is supported in part by the National Natural Science Foundation of China under contracts Nos. 10491300, 10225524, 10225525, 10425523, the Chinese Academy of Sciences under contract No. KJ 95T-03, the 100 Talents Program of CAS under Contract Nos. U-11, U-24, U-25, the Knowledge Innovation Project of CAS under Contract Nos. U-602, U-34 (IHEP), the National Natural Science Foundation of China under Contract No. 10225522 (Tsinghua University).

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